Technical Report 1067

A Prototype Procedure for Optimizing Training Strategies

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14. ABSTRACT *(Maximum 200 words)*:

For military units to be combat ready, they must be proficient in a collective set of tasks trained at various events. This report presents a research tool called the Training Strategies Optimization Prototype (TSOP) that shows potential to aid commanders in making decisions about how to improve strategies and schedules of training. TSOP was developed to determine whether available Army training data are adequate for systematically deriving alternative training strategies to meet commanders' needs. The prototype uses Army battalion-level units, but is adaptable to scheduling problems at other echelons within the Army, for other services, and even for joint applications.

This report illustrates TSOP's ability to provide the decision maker with an analytical means by which to schedule training events while considering both performance requirements and resource constraints. In many cases, the maximum level of troop proficiency may be attained through more than one combination of training events. TSOP is designed to allow the decision maker to identify the training strategy to attain and sustain troop proficiency within available resources.

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A Prototype Procedure for Optimizing Training Strategies

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FOREWORD

U.S. Army commanders are required to maintain unit combat readiness at all times. To achieve readiness, a variety of training methods are available, each offering training in necessary skills. However, limited financial and material resources affect the choices. Thus, a commander's challenge is to maintain readiness and overall troop proficiency by selecting strategies from a variety of training methods, for a finite scheduling cycle within resource limitations.

This research and development report addresses the scheduling problem. It presents an analytical prototype to aid commanders in the process of determining optimal training strategies. The prototype is designed for the U.S. Army, but could be adapted for use elsewhere in the Armed Forces by modifying the input data.

This report is part of a programmatic effort by the U.S. Army Research Institute for the Behavioral and Social Sciences to develop methods for designing combined arms tactical training strategies. It supports efforts by the U.S. Army Training and Doctrine Command and the Deputy Chief of Staff for Operations and Plans to increase the objectivity and reliability with which commanders schedule resources for collective training. The report describes a computer-based method, evaluates if it can satisfy the Army's needs, and illustrates how it works with examples.

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A PROTOTYPE PROCEDURE FOR OPTIMIZING TRAINING STRATEGIES

EXECUTIVE SUMMARY

Research Requirement:

To achieve combat readiness, unit commanders must optimize overall troop proficiency by selecting strategies from a variety of training methods within resource limitations. This research develops a prototype for optimizing training strategies, and investigates whether available Army training data are adequate for computer-based methods of deriving training strategies to meet commanders' needs.

Procedure:

A computer-based aid for commanders called the Training Strategies Optimization Prototype (TSOP) was evaluated using training tasks and resources for Army battalion-level units. Modifications are possible for other echelons within the Army, for other Services, or for Joint applications. The procedure had three steps: (1) identify a representative set of collective tasks for strategies, (2) determine the criteria for evaluating the performance effectiveness and costs of alternative training methods, and (3) evaluate an optimization method as a means to provide strategies that satisfy the Army's type of scheduling problem.

Findings:

Evaluation of TSOP identified an optimal training strategy using sample performance and resource data including: initial skill proficiency, skill degradation times, training method utility, training method costs, and resource availability. When these data were changed, TSOP provided different strategies as evidence of its sensitivity to the input variables.

Utilization of Findings:

TSOP provides the basis for a major breakthrough in developing collective training strategies. It identifies how to derive training strategies that optimize unit performance within available resources. The prototype is sensitive to changes in training conditions and can be tailored to commanders' needs. A production system based on the current prototype could serve as a valuable aid for making decisions about when and how to train. It would enable commanders to make the most efficient use of training resources. Such a system could also aid commanders in determining the achievable proficiency level within available resources.

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Introduction

Statement of Operational Problem

For the U.S. Army to be effective and efficient, every Army unit must be proficient in a collective set of tasks. The challenge is to identify training strategies--the selection and sequencing of training methods--that achieve training readiness. The Training Strategies Optimization Prototype (TSOP) was developed for systematically deriving alternative training strategies to meet commanders' needs. This report discusses the design and evaluation of TSOP and its ability to derive efficient training strategies, given available training data.

An ideal goal is to attain and maintain optimum levels of proficiency for all mission essential tasks by employing the most effective training methods at the appropriate times. However, because resources are limited, the Army has to efficiently use available training methods to achieve the highest practical levels of training readiness. According to Army Regulation 220-1, training readiness is defined as a commander's estimate of "the number of training days needed for his unit to achieve full proficiency in mission essential tasks." For example, a Battalion unit that can achieve full proficiency within 14 days is rated as T-1 level. It also is possible for resource shortfalls to prevent necessary training to achieve or maintain the highest proficiency. TSOP can assist unit commanders in determining the achievable proficiency level within available resources.

There are many deterrents to attaining and maintaining a high degree of training readiness. Skills degrade over time if not practiced and refined (Hagman & Rose, 1983; Rowatt and Schlechter, 1993). Personnel turnover decreases unit readiness. Even internal turbulence, such as promotions within a unit, can have detrimental effects (Oliver *et al.*, 1996). For example, the promotion of a tank gunner to commander of another vehicle may precipitate a series of related moves. At a minimum, two tank crews will have lost their cohesiveness, and will require additional training. In addition, budgets limit the type and amount of training that can be done. For example, artillery units cannot afford to fire an unlimited amount of ammunition to maintain proficiency. Crew drills, fire direction control procedures, and forward observer skills quickly degrade if not practiced. There also is the problem that training facilities and ranges may not be available when needed. Constraints and the complexities associated with training resource allocation underline the need for a quantitative scheduling method incorporating the following variables: initial skill proficiency, training method utility, skill degradation, training method costs, and resource availability.

Research and Development Background

The current program to quantify alternative training strategies follows earlier Army efforts to optimize training design and use. These efforts focused on training devices and simulations. For example, Bickley (1980) developed equations to select optimal combinations of

simulators and actual equipment trainers (AETs) for helicopter pilot training. Powers *et al.* (1975) determined, from empirical data, optimal combinations of simulator and live-fire tank crew gunnery training. Hiller, McFann, and Lehowicz (1994) established the value of preceding National Training Center (NTC) rotations with similar field exercises at home station. Holz, Hiller, and McFann (1994) measured how well units used principles of planning (including scheduling) in FM 25-100 and several force-on-force missions at NTC. These were invaluable, fundamental contributions to the research literature on training design quantification.

The earlier work, however, did not result in prescriptive, standards-based methods for allocating and scheduling collective training resources. The need to go this further step provided the rationale for the current ARI program on quantification of training strategies. The value of successfully achieving that step is suggested by the results of Holz *et al.* (1994) which indicate that units following prescribed Army doctrine in developing training plans are more likely to conduct successful missions at NTC than those that do not follow the doctrine.

Research that uses the Combined Arms Training Strategies (CATS) to address standards-based training methods is currently near completion at ARI (Keenan *et al.*, draft, 1997). This project aims to establish prescriptive training data dependent upon each battalion's level of proficiency in critical skill areas. The content of the data includes utility measures for each training method applicable to each skill area. The CATS data also include the estimated degradation times for each skill area if the battalion does not receive relevant training. It is believed that such CATS data could provide a means for developing training strategies, tailored to each battalion's proficiency characteristics, to optimize proficiency through training.

TSOP research was conducted to determine if a computer-based scheduling method could be designed using available data, such as from CATS, to help units better schedule training. In the past, training method scheduling has been based largely on the judgment of the commander. Although this approach has generally proved to be effective, judgment alone may not suffice in determining the strategies which provide the best training within limited resources. One intent of the TSOP research was, accordingly, to determine if available data are adequate for computer-based methods of deriving training strategies.

Method

In order for an analytical approach to provide accurate and useful results, the method must fully address the problem given the data available. Several methods were evaluated to assess the extent to which each one meets these criteria. This section reviews: a) methods according to the problem criteria; b) selection criteria for the best method; and c) components of the analytical approach.

The inputs to TSOP are initial proficiency, training method utility, skill degradation, training method costs, and resource availability; output is an optimal training strategy -- a selection and sequencing of appropriate training exercises to attain optimum proficiency. For the

purpose of this discussion optimum proficiency is the greatest or maximum number of skill-months that a unit can sustain at the fully trained level. Each skill area receives equal weight. Optimum proficiency could, alternatively, require only critical areas to be fully trained, allowing other skill areas to be partially trained. TSOP, however, identifies the strategy that sustains the maximum number of skill-months at the fully trained level. The output not only includes the strategy that optimizes proficiency, but it also includes the strategy that minimizes costs while simultaneously optimizing proficiency.

Identification of TSOP Requirements

It is true for all analyses that the output is only as good as the input. In the context of developing an analytical approach to evaluate training strategies, the input consists of measures of performance, training method utility, training costs, and resource availability. Performance is defined as (a) initial proficiency in clusters of mission essential tasks referred to herein as skill areas, and (b) degradation estimates of skill loss over time. These measures of performance are the most difficult inputs to obtain. Measures of performance are essential to understanding proficiency, but they also are extremely difficult to quantify.

Initial research was based on obtaining measures of performance that follow continuous curves of learning and forgetting. Each training strategy should result in a set of curves dependent on the mix and sequence of the training methods employed. The best strategy would optimize overall proficiency throughout a training cycle. Learning curves can represent the percent of previously unattained proficiency that is achieved through training. However, the data do not exist. In fact, the appropriate measures for obtaining the data are uncertain, so this approach was abandoned.

In order to properly define a relationship between training and performance, TSOP must adopt a consistent method to measure a unit's proficiency in a given skill area. The challenge became to identify practical performance measurements for units of collective training. Standards for the current Army training system suggested an answer. The performance measurement process begins when a commander assesses his unit's capability on mission essential tasks compared to Army standards. Standards for many tasks are found in the applicable Army Training Evaluation Plan - Mission Training Plan (ARTEP-MTP or AMTEP). Within the AMTEP, proficiency is measured as "T" for fully trained, "P" for needs practice, or "U" for untrained. Tasks are evaluated for training based on the most recent appraisal of a unit's proficiency which may be generated from the After Action Reviews (AARs) of previous training methods. The assessment of collective training is crucial to evaluating a unit's ability to execute its mission essential tasks and is used to plan future training. It is assumed that a commander's assessment of training according to the T-P-U system is consistent and accurately reflects the overall proficiency level of the unit.

Selection of an Analytical Method

Several methods were evaluated to determine if each met the requirements for the Army's training problem. Methods requiring non-existing or unavailable data were abandoned. Similarly, methods that do not fully address the problem were abandoned as well. For example, Data Envelopment Analysis was abandoned because it does not generate a training strategy, but rather evaluates current strategies and recommends improvements on those strategies. This is not consistent with the aim of TSOP, which is to provide decision makers with an analytical tool to establish *future* training strategies, rather than evaluate *prior* strategies. The Max-Min method was evaluated as a potential candidate but was rejected because, although it does determine which methods should be included in the training strategy, it does not provide the sequence of those training methods.

An analytical method that fully addresses the training problem and is compatible with available Army data for developing training strategies is Linear Programming (LP). This method optimizes some objective, which is a function of various decision variables. A typical example that this method addresses is the optimization of the objective "profit" in a manufacturing business. "Profit" in this example is a function of the variables "items produced," "cost per item," and "items sold." Optimum profit is restricted by constraints, such as "items produced must be less than 1000." An optimal solution must satisfy all constraints and provide the maximum overall objective. A graphical representation and interpretation of an LP formulation is provided in Appendix A.

Mixed Integer Linear Programming or, more commonly, Mixed Integer Programming (MIP) showed the best promise for accommodating the Army's T, P, and U training data. MIP is an extension of LP involving the maximization of problems where part or all of the solution is restricted by integer values. MIP searches only for solutions which satisfy this integer requirement. The Army's scheduling problem clearly is integer because: (a) during any given month one training method typically is selected; (b) it is possible to select *no* training method in a given month, but it is not possible to select a fraction of a training method; and (c) performance is assessed as T, P, or U and can not equal some combination thereof. Thus, the Army's scheduling problem is a MIP problem and, specifically, a 0-1 MIP problem. A 0-1 MIP problem is binary in nature, as only two values are acceptable for the integer variables (in this case, "implement this training method in this month", and "do not implement this training method in this month"). Accordingly, TSOP uses MIP in its approach to locate the optimal solution.

Components of the Optimization Prototype

TSOP encompasses three general components: the input, the method, and the output. The input includes initial skill proficiency, skill degradation times, training method utility, training costs, and resource availability. The method defines the procedure by which an optimal solution is obtained. The output is the resulting training schedule that the method generates from the relevant inputs, and the expected proficiency levels which will result from implementing the schedule.

This section discusses each component of the prototype and presents an example of how TSOP works for an armor battalion training problem. In this example, the battalion is required to maintain maximum proficiency levels in 15 skill areas and has seven methods available to train the troops (see Table 1). Although the discussion follows a specific example, it is designed to illustrate the prototype's functional versatility.

Table 1
U.S. Army Training Methods and
Skill Area Clusters of Mission Essential Tasks

Training Methods[a]

Staff Exercise (STAFFEX)
Map Exercise (MAPEX)
Tactical Exercise Without Troops (TEWT)
Fire Coordination Exercise (FCX)
Command Post Exercise (CPX)
Command Field Exercise (CFX)
Field Training Exercise (FTX)

Skill Areas

Defend Against Air Attack
Take Active/Passive Air Defense Measures
Command Group Operations
Plan for Combat Operations
Direct and Lead Units During Preparation for Battle
Direct and Lead Units in Execution of Battle
Coordinate/Synchronize/Integrate Fire Support
Employ Mortars
Employ Field Artillery
Employ Close Air Support
Perform S2 Operations
Conduct Intelligence Planning
Collect Combat Information
Process Intelligence Information
Disseminate Intelligence Information

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[a] The training methods are described in Appendix B.

TSOP Inputs

<u>Initial proficiency</u>. TSOP uses AMTEP standards for performance measurement to assess the unit's initial proficiency. Six assumptions are inherent to AMTEP's T - P - U performance scale and are, accordingly, inherent to TSOP as well: (a) proficiency levels are discrete and, accordingly, it is possible only to assess a unit's proficiency as one of the three levels and not in-between them; (b) a level of T represents maximum proficiency; (c) a unit's proficiency level never can degrade below U; (d) a unit's proficiency level is specific for a given skill and is independent of training in another; (e) proficiency levels, both initial and post-training, reflect the level of the unit as a singular entity and do not necessarily represent the skill level of each and every individual soldier in that unit; (f) when a unit's proficiency in a specific skill area improves as a direct result of a training method, the increase is represented as a step function given the T, P, and U assessments. (The increase in proficiency could likely be better represented as a learning curve, but data for this are not generated by unit commanders).

<u>Training method utility</u>. An essential input in determining the optimal training strategy is training method utility. Measures of training method utility are estimates of the amount that proficiency should improve after using a training method. A given training method can (a) increase a unit's proficiency in one or more skill areas, allowing the unit to move from U to P, from U to T, or from P to T, (b) sufficiently sustain a unit at its current proficiency level for a given skill area, delaying its potential degradation to a lower level, or (c) offer no benefit to the unit. A set of matrices was developed by BDM, Inc. (Keenan *et al.*, draft, 1997) that shows the utility of different training methods for components of a combined arms battalion task force. These Combined Arms Training Strategies (CATS) matrices provide a standardized protocol for training given current proficiency levels. TSOP builds its capability in part on CATS, as well as on other inputs such as training method costs.

Figure 1 shows an example of training method utility based on the CATS data. Training method utility was derived according to the conventions described in Appendix C. It illustrates, for each initial proficiency level, any applicable increases in proficiency that would result from each training method. Training methods whose utility characteristics are identical to those of other training methods are excluded from this figure to avoid redundancy.

To better understand what the table shows, focus on the skill area Defend Against Air Attack. A unit initially at the T-level can train with an FTX, CFX, FCX, or CPX and remain fully trained. Such sustainment training reinforces skill proficiency, offsetting any elapsed degradation time. In contrast, a MAPEX, TEWT, or STAFFEX would provide no benefit for the particular skill area, and any elapsed degradation over time will continue. A different unit, initially at the P-level, can train with an FTX, CFX, FCX, or CPX to become fully trained. However, training with a MAPEX or TEWT results in the same partially trained level. A STAFFEX offers no utility to this unit and, hence, the unit's skill degradation will continue to accumulate over time. A completely untrained unit will become partially trained if it is trained with an FTX, CFX, FCX, CPX, MAPEX, or TEWT. A STAFFEX, once again, offers no utility. In contrast, the skill area Command Group Operations can be trained only by an FTX, regardless of its initial proficiency level.

Skill degradation. Another input to training strategy selection is skill degradation. One objective of training is to increase proficiency in a given skill area; another is to *sustain* proficiency in a given skill area. A unit at a certain proficiency level will remain at that level only with periodic relevant training. Otherwise, the unit degrades to a lower proficiency level due to (a) the loss of skill resulting from periods without training, and (b) personnel turbulence due to reassignments within the unit or departure from the battalion. In the example problem,

		Post-Training Proficiency Level "-" indicates no utility from training, so proficiency continues to degrade No Change (i.e. P→P) indicates skill sustainment						
Skill Areas	**Initial Proficiency**	Training Method						
		FTX	CFX	FCX	CPX	MAPEX	TEWT	STAFFEX
Defend Against Air Attack	T	T	T	T	T	-	-	-
	P	T	T	T	T	P	P	-
	U	P	P	P	P	P	P	-
Active/Passive Air Defense Measures	T	T	T	T	T	-	-	T
	P	T	T	T	T	P	P	T
	U	P	P	P	P	P	P	P
Command Group Operations	T	T	-	-	-	-	-	-
	P	T	-	-	-	-	-	-
	U	P	-	-	-	-	-	-
Plan for Combat Operations	T	T	-	-	-	-	-	T
	P	T	-	-	-	-	-	T
	U	P	-	-	-	-	-	P
Direct and Lead Units During Battle Prep	T	-	T	T	T	-	-	T
	P	-	T	T	T	P	P	T
	U	-	P	P	P	P	P	P
Direct and Lead Units in Battle Execution	T	-	T	T	T	-	-	T
	P	-	T	T	T	P	P	T
	U	-	P	P	P	P	P	P
Coord, Synch, and Integrate Fire Support	T	T	T	T	T	-	-	T
	P	T	T	T	T	P	P	T
	U	P	P	P	P	P	P	P

Figure 1. Training Method Utility. (Training method utility presented in this figure is based on BDM's CATS data.)

each skill area degrades from T to P in 3 months, and from P to U in 4 months based on BDM's CATS data. These common rates of decay, as extracted from the CATS data, are assumed for the current example.

The primary assumption for skill degradation is that a unit not trained with a method to enhance or sustain proficiency after a specific length of time will degrade to the next lower proficiency level. In addition, it is assumed that a unit will degrade from T-level to P-level more rapidly than it will degrade from P to U. The rationale is that a fully-trained unit will lose some

of its skill mastery more rapidly than a partially-trained unit will lose *all* proficiency in the skill. These changes are step functions because the discrete ratings provide no data about the gradual learning and forgetting that actually must occur.

Training method costs. Some training methods provide better or stronger training than others--either in terms of enhancing overall proficiency levels or by providing training utility for a greater number of skill areas. However, it should not intuitively be assumed that a stronger method is always preferable to a weaker method. A strategy that mixes stronger and weaker methods can optimize training if different training methods have different costs, which is generally the case. Weaker methods can often train certain skill areas quite well. Stronger training methods often are much more costly than weaker methods and, accordingly, should be scheduled strategically to realize maximum benefit. A strategy that mixes stronger and weaker methods can optimize training costs, and TSOP must stay within cost constraints to be practical.

The total cost of implementing each training method must be known before determining a feasible strategy. A training method might incorporate costs associated with some or all of the following: equipment, supplies, maintenance, transportation, fuel, opposing forces, simulation, communications, and ammunition. A field exercise is more costly than an exercise conducted in garrison due to additional costs of equipment, supplies, transportation, and so on. A simulation exercise is often the most economical, provided that simulators already are available. In such cases, the cost of an exercise must include operating costs of the simulators, as well as an amortized portion of the purchase cost and any development costs. Salaries of participating troops are not included in training costs since this is fixed and independent of training method. However, if opposing forces are required, the corresponding personnel cost is part of overall training costs. TSOP needs to incorporate all costs inherent to a training method.

The training method cost data that TSOP used for the example problem applies to FY1998[1]. They include mileage costs for vehicles, hourly operating costs for equipment, and ammunition costs. Table 2 provides a cost summary estimate for training methods (see Appendix D for details). More detailed estimates will be needed to more accurately reflect actual

Table 2
Training Method Cost Summary

TRAINING METHOD	COST ($)
FTX	651,728
CFX	239,717
FCX	10,843
CPX	1,220
MAPEX	1,220
TEWT	1,220
STAFFEX	1,220

[1] Cost estimates are based on The Training Resource Model (TRM) maintained by CACI, Arlington, VA.

training method costs. Currently, for example, data do not differentiate between CPX, MAPEX, TEWT, and STAFFEX training. The data provided in Table 2, although incomplete, are sufficient to demonstrate the capabilities of TSOP.

One feature of TSOP is that the decision maker can incorporate a cost ceiling. It may be entered as an overall budget constraint (over an entire planning horizon), a quarterly budget constraint, or both. Then, the resulting training strategy will not exceed a maximum cost.

Resource availability. Another input to TSOP is the set of months during which each training method is available. It is, quite obviously, not possible to train a unit by a given training method unless it is available. If, for example, multiple battalions vie for the same training facility, then only one can use it. The example problem presents the situation where all training methods are available at all times to establish a baseline "best possible" strategy before introducing limits to the various inputs.

TSOP Method

TSOP uses an analytical method to identify a training strategy that provides optimum proficiency. To determine which combination of training methods will provide the optimum degree of proficiency across all skill areas is a complex problem. The sample problem includes 15 skill areas, 7 training methods, and 3 levels of training proficiency, over an 18-month planning cycle. There are over 18×10^{15} possible training strategies -- that is, 8 possible methods to select from including the option not to train, for each of 18 months. The optimal strategy depends on combining initial proficiency, degradation times, and training method utility, to determine the number of months which the unit is expected to sustain at the maximum number of T skill-months, with cost and availability constraints imposed as necessary.

TSOP uses Mixed Integer Programming to locate the optimal training strategy and calculate the corresponding proficiency levels throughout the planning cycle. General Algebraic Modeling System (GAMS) programming language was used to code the prototype (see Appendix E for the code). TSOP locates *an* optimal training strategy, but not necessarily *the only* optimal strategy. In many cases, multiple optimal strategies can exist. Each of the optimal strategies will maximize overall proficiency levels over the planning cycle. Additional constraints and multiple objectives (such as cost minimization which will be discussed later) reduce the number of optimal strategies, often to one unique strategy.

TSOP Output

As previously discussed, TSOP solves the training scheduling problem using the initial skill proficiency, skill degradation times, and training method utility as inputs, along with the restrictions imposed by costs and resource availability. The prototype's output is an optimal training strategy for an 18-month planning cycle. However, the planning cycle can be changed to suit the individual problem situation. An 18-month cycle is used in the prototype application because discussion with various training specialists indicated that such a time frame would be most appropriate when planning training schedules. These same discussions revealed that, on

average, one training method could be employed each month. Hence, the prototype is designed according to one-month planning increments that can be modified to be more or less frequent as necessary.

The initial output is a single, optimal planning strategy, which will assure maximum proficiency levels across all skill areas. The format is a table that lists the appropriate training methods to employ during each of the months of the 18-month planning horizon. The prototype also generates a table of expected proficiency levels, for each skill area and during each month, which will result upon implementation of the optimal strategy. Because there often will be multiple strategies that maximize proficiency, the prototype can be run again while minimizing costs without compromising overall proficiency. The format of this final output is identical to the initial output: a table which lists the appropriate training method to employ during each of the months of the planning cycle. It should be noted that the optimal strategy may recommend no training in particular months. This is because a battalion remains proficient in a skill area, without training, before degrading to a lower level. Such information is useful to the unit's commander to plan schedules for the upcoming 18-month period.

Results and Discussion

TSOP identified an optimal training strategy using the sample data discussed previously: initial skill proficiency, skill degradation times, training method utility, training method costs, and resource availability. No cost ceilings were included, but some FTX training requirements were imposed for the following reasons: (a) an FTX offers a high level of quality relative to other methods, which may not be sufficiently reflected in the training method utility data available; (b) an FTX is expensive in costs and logistics; and (c) the time for planning an FTX and for post training review limits its practical frequency. Accordingly, the example problem had to include at least one FTX in the optimal strategy, but FTX scheduling was limited to no more than one during any nine-month period.[2]

Figure 2 shows an example training strategy that TSOP identified to maximize proficiency. The highest possible proficiency total would be 270 skill-months at the completely trained (T) level. This value is obtained by multiplying the total number of skill areas (15) by the number of months in the planning cycle (18), to get total number of Ts possible throughout the duration of the cycle. The optimal strategy will maintain complete training proficiency in 236 of the 270 possible skill-months, or 87 per cent of the time; 100 per cent is not attainable since *no* method trains every skill. Tradeoffs were necessary to best train across *all* skill areas. This training strategy would cost $719,360 to implement. As mentioned previously, there are usually many different strategies that will maximize proficiency. One approach to selecting among multiple strategies would be to select the strategy for which a unit, when not at the T-level, is at the P-level most of the time rather than at the U-level. Another approach is to minimize the overall cost of implementing a strategy once the maximum attainable proficiency has been

[2] Army policy currently schedules an FTX only every 18 months. Nine-month intervals were selected for this example to demonstrate the prototype's adaptability to a training exclusion window .

determined. Figure 3 presents the strategy which minimizes training costs while maximizing proficiency. This strategy achieves the maximum attainable proficiency measure of 236 skill-months at the fully-trained level, but costs only $666,368 to implement.

Figure 4 graphically presents, for each of the skill areas, the proficiency level forecasts that would be attained throughout the 18-month planning horizon if the strategy in Figure 3 were implemented. It should be noted that the proficiency-level forecasts would differ for the schedules identified in Figures 2 and 3 even though the total sum of *T-levels* are equal. Inspection of the sample inputs and the optimal training strategy presented in Figure 3 provides insight into TSOP's logic.

According to the training method utility measures (see Figure 1), a CFX, FCX, CPX, MAPEX, and TEWT all provide training utility for each skill area except for two: Command Group Operations and Plan for Combat Operations. The MAPEX and TEWT only provide sustainment training at the P-level, while a CFX, FCX, or CPX can advance unit proficiency to the T-level. Therefore, the maximum number of unit-months at the T-level is achievable only with a CFX, FCX, or CPX. However, the objective is not only to maximize proficiency, but to minimize training costs as well. For that purpose, the CPX is preferable to the CFX or the FCX, which provide training utility identical to the CPX but have higher training costs. Only an FTX provides training utility for the skill areas for which the CPX provides none (Command Group Operations and Plan for Combat Operations). Intuitively, an alternating schedule between FTX and CPX would minimize the cost of training methods that attain the highest possible proficiency level. This is not possible because FTXs would have to occur too frequently. Accordingly, the STAFFEX is recommended since it provides training utility to Plan for Combat Operations.

TSOP selects a strategy which alternates STAFFEX and CPX, so that skill areas which do not benefit from a STAFFEX (such as Defend Against Air Attack) benefit from CPX training, while skill areas which do not benefit from a CPX (such as Plan for Combat Operations) benefit from STAFFEX training. With a 3-month degradation time for each skill area, the strategy can rotate among CPX training, STAFFEX training, and no training, without ever degrading to a lower proficiency level.

Figure 2 illustrates different effects of training frequency with no cost limitations. For example, the strategy includes overtraining with a MAPEX in month 5 and a TEWT in month 18. It is considered overtraining because the skills should not degrade that quickly, yet the strategy includes training anyway. In contrast, the repeated training in months 1 through 4 is essential to initially increase untrained units to the fully-trained level. The implementation of an FTX in month 16 fulfills many training needs, such as increasing the unit's proficiency in Command Group Operations from U to P. However, with an FTX scheduled no more than once every 9-month period, it cannot fulfill training needs of skills that degrade in less than nine months. Frequency of training is a major consideration in choosing strategies.

The sample problem, of course, is based on inputs derived from less precise and less complete data than are possible. Better assessments will occur as training methods are better differentiated according to the varied benefits each provides and cost estimates are more

Proficiency Measure: 236
Cost: $719,360

Month	Training Method
1	FCX
2	FCX
3	STAFFEX
4	FTX
5	MAPEX
6	STAFFEX
7	FCX
8	STAFFEX
9	CPX
10	STAFFEX
11	FCX
12	STAFFEX
13	
14	FCX
15	STAFFEX
16	CPX
17	STAFFEX
18	TEWT

Figure 2--Optimal Training Strategy, Max Proficiency

Proficiency Measure: 236
Cost: $666,368

Month	Training Method
1	CPX
2	CPX
3	STAFFEX
4	STAFFEX
5	CPX
6	
7	STAFFEX
8	CPX
9	
10	STAFFEX
11	CPX
12	
13	STAFFEX
14	CPX
15	
16	FTX
17	CPX
18	

Figure 3--Optimal Training Strategy, Max Proficiency & Min Costs

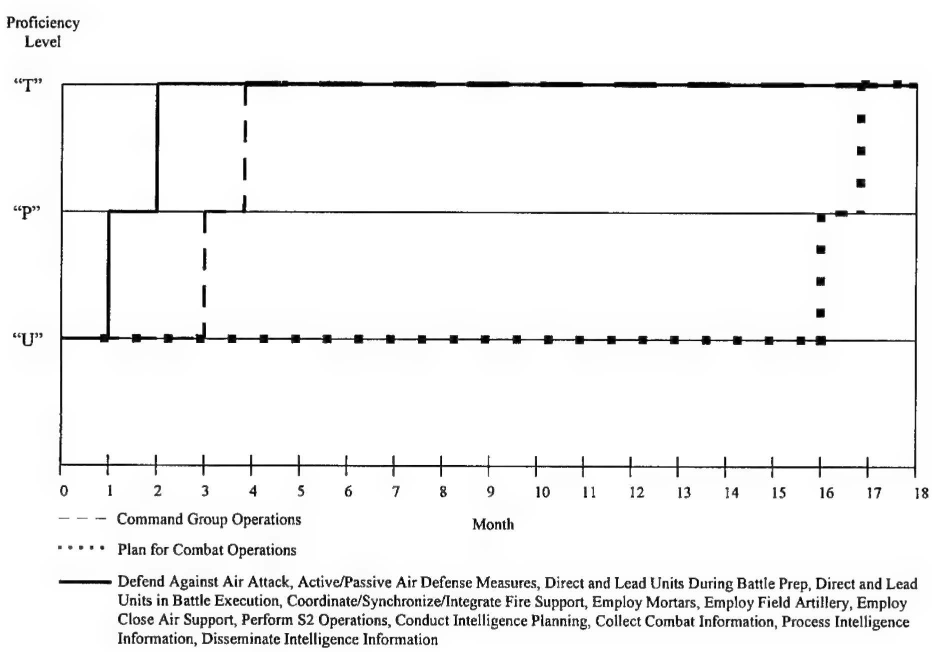

Figure 4--Proficiency Forecasts For Each Skill Area. (Assumes strategy in Figure 3).

accurate. Then, intuitive identification of an optimal strategy will be significantly more complex. This is where TSOP can offer significant utility to the training strategy selection process. TSOP identifies an optimal training strategy, ensuring maximum overall proficiency of the troops across all skill areas throughout the planning cycle, for the minimum overall cost.

Sensitivity Analysis

The example problem illustrated how TSOP could be applied using specific inputs. A related factor is how sensitive the output is to changes in the input. This section describes sensitivity of TSOP to changes in initial skill proficiency, skill degradation times, training method costs, and resource availability, as well as the incorporation of cost ceilings. In one case, the baseline example, both the initial results (proficiency maximization) and the final results (proficiency maximization combined with cost minimization) are included to illustrate the significant benefit derived from cost minimization. For all other variations, the discussion presents only the final results--those obtained once proficiency is maximized and costs are minimized.

<u>Baseline Problem</u>. In order to accurately evaluate TSOP's sensitivity to parameter changes, first a baseline problem was developed with no constraints, including no limits on frequency. With the exception of training method costs, the inputs are identical to those discussed previously: initial proficiency for each skill area is assumed to be at the U-level, training method utility is identical to that which is summarized in Figure 1, unlimited resource availability is assumed, and degradation times are assumed to be 3 months to degrade from T to P and 4 months to degrade from P to U.

<u>Scale of Costs</u>. Training method costs were modified to better differentiate among methods because the actual available data do not indicate cost differences among CPX, MAPEX, TEWT, and STAFFEX. To differentiate these methods, cost estimates were based on qualitative descriptions provided in the FM 25-101 and FM 25-4, and refined through discussions with Army personnel[3].

Each training method was assigned a cost value along a scale ranging from 0 to 100, representing the relative cost of that training method compared to each other training method. These values are not actual training method costs, but rather represent the costs of each method relative to each other method. The method with the greatest overall costs (FTX) is given the maximum value of 100, and each other method is weighted relative to that. For example, a CFX (with a cost of 70) is predicted to cost about 70/100 or 70% as much as an FTX. Similarly, a STAFFEX is predicted to cost 35/70 or half as much as a CFX, and so on. The estimates (Table 3) better differentiate among costs of training methods, but do not represent precise relative weights. The cost scale ranges from 0 to 1800, where 1800 would represent the cost of attending the most costly training exercise--an FTX--every month over the 18-month planning cycle.

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[3] The comparative costs of the training methods were refined by LTC Tony Davis, U.S. Army Reserve, and LTC Kurt Langenwalter, Technical Director's Office, ARI.

Table 3
Modified Cost Estimates

TRAINING METHOD	COST
FTX	100
CFX	70
FCX	55
CPX	68
MAPEX	5
TEWT	40
STAFFEX	35

TSOP identified an optimal strategy that will maintain the unit at the fully trained (T) proficiency level for 251 of the 270 possible skill-months, or 93 per cent of the time. The decrement arises because the initial proficiency levels for each skill area are assumed to be "U," and two months are required to train the troops to the T proficiency level. If the initial proficiency levels are P or T, then overall proficiency will be much closer to the ideal of 270 skill-months, a case discussed later in this section. The total cost of implementing the optimal training strategy, based on data in Table 3, will be 1301.

TSOP was subsequently used to identify a strategy that not only maximizes proficiency, but minimizes costs as well. This strategy would maintain the highest attainable proficiency level--251 of the 270 possible skill-months--as would the initial strategy, but at a cost of 855 compared to 1301 for the initial strategy.

Sensitivity to initial proficiency. Initial skill proficiency of the unit contributes significantly to overall proficiency levels. A unit already at the T-level will require training to sustain that T-level, but will not need immediate training to reach the T-level. Accordingly, a unit that begins the training cycle already trained to some extent should be able to achieve a higher total proficiency level than one that initially is untrained. To verify this, the initial proficiency matrix was modified so that every skill area was T rather than U. The resulting strategy maintains the troops at the T-level for a total of 270 out of 270 possible skill-months, at a cost of 810. The increase in overall proficiency and decrease in costs result because no initial training is necessary to raise proficiency to the T-level. This analysis suggests that, once a unit is trained to the T-level, subsequent training can feasibly maintain complete proficiency at all times.

Sensitivity to degradation time. Degradation time for skills also is a key input in determining the optimal strategy. Longer periods of degradation time would allow less frequent training to sustain the current T-levels of proficiency. Conversely, shorter periods of degradation would require more frequent training to ensure maximum proficiency in each skill area. The baseline example was modified so that degradation times (and only degradation times) were reduced to one month for each skill area. The optimal strategy results in a total proficiency measure of 219 of a possible 270, and a cost of 1078 out of 1800. The significant reduction in overall proficiency emphasizes the impact of degradation times on unit performance.

Sensitivity to budget constraints. The other type of resource limitation imposed on training scheduling is budget constraints. The baseline example included no budget limitations in order to determine the highest total proficiency attainable. That result was a total proficiency of 251, with a cost of 855. If an overall budget and quarterly budget are imposed, the feasible strategies will change. Consider, for example, a budget of 750, and budgets for quarters 1 through 6 of 95, 200, 150, 0, 300, and 70, respectively. A total proficiency measure of only 222 is attainable for a cost of 743.

Sensitivity to resource availability. All prior results were obtained assuming unlimited physical resource availability. Sample results illustrate the capability of TSOP to incorporate limitations on resources. Unavailability of training facilities means that the desired training method cannot be implemented at the desired time. An example of limited training facilities (see Figure 5) produced a total proficiency measure of only 229 for a total cost of 796. Such resource restrictions limit the feasible training strategies and negatively affect overall proficiency levels.

Sensitivity analysis conclusions. As the examples and sensitivity analyses illustrate, TSOP can be adapted to a wide range of requirements, and the optimal training strategy will be tailored to them. In this way, the method serves as an ideal tool for determining training schedules. It can be used initially without constraints to determine the best results possible, and then it can be manipulated as desired to evaluate how changes in the problem environment will affect the end results.

	FTX	CFX	FCX	CPX	MAPEX	TEWT	STAFFEX
1			X				
2			X		X		
3	X				X		
4							
5		X					
6							X
7							X
8				X			
9							
10	X						
11							
12					X	X	
13	X				X		
14							
15		X					
16							X
17							X
18				X			

Figure 5--Limited Resource Availability.

Future Training Potential

The previous section began with a baseline example that included no constraints. The resulting maximum proficiency was 251 skill-months in contrast with the initial problem described earlier in the Results and Discussion section, with a maximum level of only 236 skill-months. The difference is due to the FTX limitation included in the initial example. TSOP was designed to allow such limits in training frequency to help military planners decide about optimal strategies.

TSOP may be used to forecast the potential effects of changing training limitations. For example, it can forecast the results if enhanced simulation capabilities or streamlined preparation capacity made more frequent FTXs or simulated FTXs practical. To illustrate this, the initial example, based on "real" planning restrictions, was altered so that no planning restrictions were included. Using the cost data derived from CACI and from the Office of the Deputy Chief of Staff for Operations (ODCSOPS), TSOP identified an optimal strategy (Figure 6) with an overall proficiency of 251, and an implementation cost of $5,886,155.[4] The prototype was run again, this time with an objective of minimizing costs while still attaining a proficiency measure of 251. This strategy (Figure 7), would cost $3,918,908 while maintaining T-proficiency for the maximum attainable 251 skill-months. Thus, TSOP has not only identified an initial

Proficiency Measure: 251
Cost: $5,886,155

Month	Training Method
1	TEWT
2	CPX
3	FTX
4	FTX
5	STAFFEX
6	STAFFEX
7	FTX
8	FTX
9	FCX
10	FTX
11	FTX
12	STAFFEX
13	FTX
14	STAFFEX
15	FTX
16	CPX
17	FTX
18	TEWT

Figure 6--Optimal Training Strategy, Max Proficiency, No Constraints.

Proficiency Measure: 251
Cost: $3,918,908

Month	Training Method
1	CPX
2	CPX
3	FTX
4	FTX
5	STAFFEX
6	
7	FTX
8	CPX
9	
10	FTX
11	CPX
12	
13	FTX
14	CPX
15	
16	FTX
17	CPX
18	

Figure 7--Optimal Training Strategy, Max Proficiency & Min Costs, No Constraints.

[4] It should be noted that the training strategy costs are presented to the nearest dollar for illustrative purposes only; they are not necessarily intended to reflect that degree of precision.

strategy that provides maximum training, but it has identified another strategy that reduces costs by nearly $2 million, without compromising any proficiency.

This training strategy is significantly different from the original, "realistic" example discussed in the beginning of this paper. Comparison between the two examples indicates that, while the *realistic* example attains a proficiency measure of 236, a unit has the *potential* of attaining a proficiency measure of 251. The potential to increase proficiency by 15 skill-months suggests ways for planners to investigate enhancements to unit training.

Perhaps there are ways to streamline the time to prepare, coordinate, and implement training to take better advantage of certain methods. In the future, technology may enable simulated field exercises at reasonable costs and reduced logistics challenges compared with current FTXs. Exercises built on technologies such as Distributed Interactive Simulation and virtual reality will supplement current training capabilities and perhaps make back-to-back virtual-field exercises practical and effective.

Another point of interest is the extreme increase in cost as FTX training increases in frequency. The 15 skill-month increase in proficiency would increase training costs nearly six times (from $666,368 to $3,918,908) versus the cost of the strategy which incorporates FTX limitations. TSOP may help the Army to weigh the tradeoff between training proficiency and training costs.

Limitations

TSOP demonstrates strong potential for identifying optimal training strategies, but some limitations should be mentioned. TSOP, in its current form, serves only as a prototype to demonstrate what is possible in training strategy selection. The prototype has the ability to determine training strategies that are optimal given training utility and cost criteria that it uses. However, the prototype relies on many assumptions and extrapolations. Additionally, it is often difficult to quantify all elements of a problem. While the data that TSOP uses is not ideal, it is sufficient for the purpose of demonstrating the potential of analytical strategy selection. Estimation and derivation are inescapable, but their effects will decrease as better information becomes available.

For example, a single value is assigned to the utility measures derived for each training method. In reality, it is difficult to represent, with a single number, all of the many components that affect utility. A commander's prior experience and motivation can affect the utility of an exercise, as can troop cohesion and integrity. Training utility will also depend on training preparations. The effectiveness of training intended for the battalion level will be compromised, for example, if individual skills are weak. Additionally, utility measures for each skill area are evaluated independently of each other skill area, whereas in reality commanders may consider the interrelationships among different skill areas. Also, all skill areas are weighted equally, which may not accurately represent the commander's assessment. If these assessments become available, they could easily be incorporated into TSOP and would increase the sensitivity of the output. Consider also that proficiency enhancement estimates depend largely on the type of unit.

Armored cavalry, tank, or mechanized infantry units may all have similar proficiency requirements, but they may differ significantly from those of artillery, combat service support, or engineering. TSOP's high level of flexibility, however, enables problem-specific changes to address such issues.

Another limitation of this prototype is that multiple strategies occur for identical data. TSOP's branch and bound approach does not locate all possible strategies because it stops the search after the first one is located. Nor is it possible to guarantee that running the prototype again will find a different strategy. This is a disadvantage if, for example, the battalion commander would like to evaluate and rank several different strategies. Modifying TSOP to locate multiple, distinct, optimal strategies may be possible, but further research into IP is necessary. If the sensitivity parameters associated with IP behave similarly to those associated with LP, then it may indeed be possible to locate all optimal solutions.

There exist two possibilities without unique solutions: a) when multiple training methods have identical costs, and b) when optimal proficiency levels are possible through various sequences of the same set of training methods. The first possibility was illustrated by the example problem that used costs from CACI where estimates did not have comprehensive cost components (such as transportation costs, personnel costs, platform and communication costs). Accordingly, costs did not adequately differentiate among training methods. The second possibility occurs when measures are equivocal: initial proficiency, training method utility, and degradation times. In this case, multiple strategies may exist if proficiency maximization is the only criterion, but once proficiency is maximized *and* costs are minimized, the strategy likely will be unique.

One final limitation is noteworthy regarding TSOP's use of LP in its problem-solving approach. In an extremely large IP problem, such as the Army's, it often is difficult (and time-consuming) to locate a solution which achieves *the* maximum objective. Therefore, a relaxed goal that is acceptable to the decision-maker probably is best. This goal may be a degree of confidence or precision, or an absolute value. For example, in exchange for the ability to obtain a solution within minutes rather than hours, a decision-maker may often be satisfied with a solution that will attain at least 99 per cent of the maximum proficiency level. Similarly, it might be desirable to obtain a solution that will result in achieving the objective +/- 5 cost units.

Refinement Toward a Production Version

This prototype demonstrates the potential of an analytical approach to training strategy selection, but would need to be streamlined before it could serve as a fully functional and efficient, stand-alone system. Additional factors may need to be incorporated into the method to address different problems and users. For example, the current prototype identifies strategies that maximize the number of skill-months that a unit is fully trained. The optimal strategy potentially might schedule no training for some skill areas, provided this lack of training is offset by substantial training in other skill areas. A commander may want to incorporate a constraint that requires every skill area to receive some training. Similarly, a commander may be more interested in every skill area being fully trained perhaps 80 per cent of the time, rather than

maximizing the overall T-level. Also, the prototype does not currently consider the necessary sequencing of exercises to develop appropriate prerequisite skills. These are all factors that could be added into a production version to tailor it to meet varying objectives.

A production system should be more efficient than the prototype. A user interface is needed so that commanders easily could tailor TSOP to specific conditions without needing programming experience with the GAMS language. Additionally, while the GAMS code has been refined significantly to manage the intensive input data described in this report, the code could be faster at solving strategies. Finally, techniques are possible to combine a two-step process into one. Currently, the prototype is run with the objective of maximizing proficiency, and then the maximum proficiency is included as a constraint in a second run which minimizes costs. Consolidation of the steps will require some research into the capabilities of GAMS and any other programming languages which might be capable of solving Goal Programming problems (see, for example, Balas *et al.*, 1996). TSOP and this discussion present the capabilities that are possible in training strategy selection, and the potential utility of a more robust version.

TSOP Demonstration

In order for TSOP to provide utility to the decision-maker, it must not only be useful but usable as well. Toward this aim, the authors had a greatly simplified computer-based demonstration of TSOP to review the steps necessary for data entry. It has a user-friendly interface between TSOP and the decision maker. The software runs on a 486 or better personal computer, was developed for research purposes only, and is not available for distribution.

Summary and Conclusions

The ultimate objective of the TSOP research was to provide a decision-maker with a recommended strategy with which to train the troops. Given numerous inputs, each of which is unique in form and function, the prototype finds the strategy which meets each of the decision-maker's criteria. A major criterion is, undoubtedly, to maximize unit proficiency. Another major criterion is to minimize training costs without compromising overall proficiency. In addition, strategy selection may be subject to quarterly cost constraints or a limited overall budget. The decision-maker may also want to include, for example, at least one FTX per planning cycle, or no more than 2 CPXs. The strategy may be subject to constraints such as a certain time interval between FTXs for planning and coordination purposes. Constraints are incorporated into TSOP, and can be edited as necessary to tailor it to specific needs. Thus, TSOP can serve as a useful aid in both general and specific training strategy selection problems.

The U.S. Army could benefit significantly from an analytical system that addresses the determination of training strategies. The current report documents the Training Strategies Optimization Prototype (TSOP), a successful approach that uses available data from Army training combined with Mixed Integer Programming techniques. TSOP provides the basis for a major break-through in deriving collective training strategies. It identifies how to derive training

strategies that maximize unit performance within available resources. The prototype is sensitive to changes in training conditions. A production version based on the current prototype could serve as a valuable aid for making decisions about when and how to train. It could help to make the most efficient use of training resources.

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Appendix A

Linear Programming

Linear Programming

Formulation of a Linear Programming (LP) problem (Winston, 1994)

Objective: Maximize $Z = f(\mathbf{X})$ (linear function of decision variables, $\mathbf{X}$)

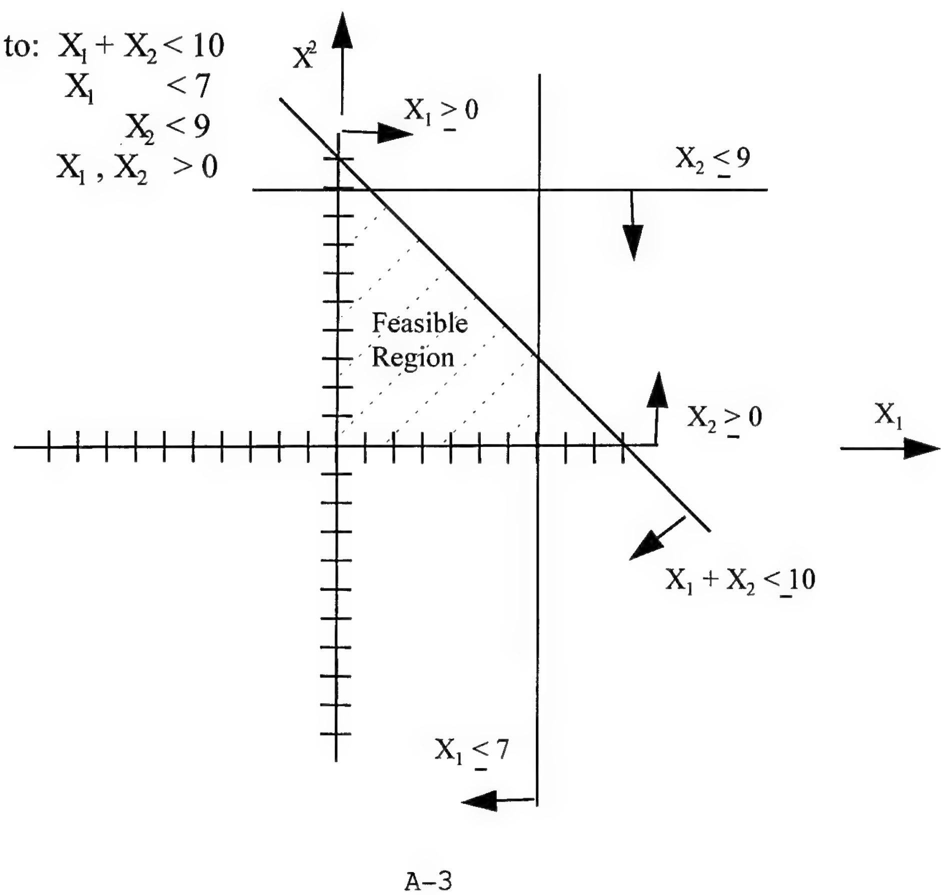
Subject to: Constraints (linear equations and linear inequalities)
Sign Constraints are possible

Example

The following is a hypothetical problem, representing the optimization of two decision variables, X_1 and X_2. X_1 and X_2 could represent, for example, $Product_1$ and $Product_2$ with production facilities limiting the total number of $Product_1$ produced not to exceed 7, the total number of $Product_2$ produced not to exceed 9, and the total number of products (type 1 or 2) produced not to exceed 10. $Product_1$ sells for \$2, while $Product_2$ sells for \$3. The linear optimization maximizes profit according to production constraints.

Objective: Maximize $Z = 2X_1 + 3X_2$

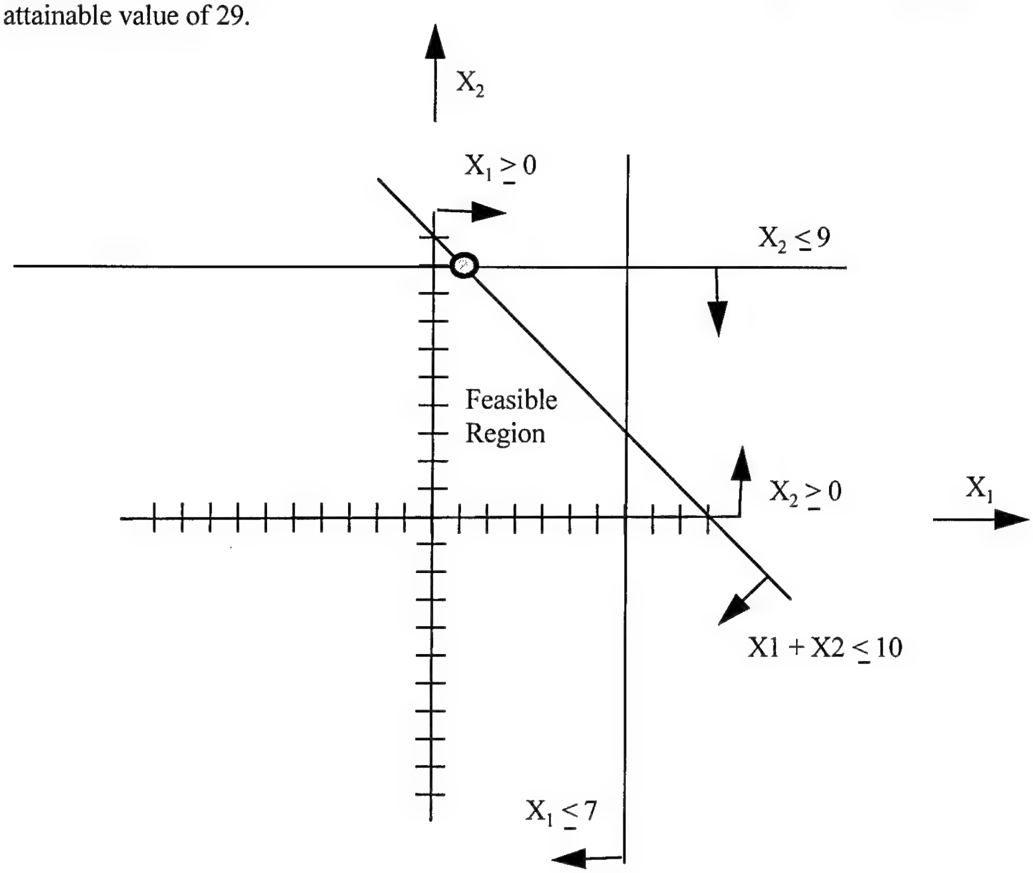
Subject to:
$$X_1 + X_2 < 10$$
$$X_1 < 7$$
$$X_2 < 9$$
$$X_1, X_2 > 0$$



Any LP that has an optimal solution will have an optimal solution at a vertex of the feasible region.

This is based upon the following characteristics of LPs (Winston, 1994).
•The feasible region of an LP will be a convex set.
•A point, P, in a convex set, is an extreme point if every line segment that lies completely within the convex set and contains the point P has P as an endpoint.
•Any LP that has an optimal solution has an extreme point that is optimal

Thus, to determine the optimal solution, each vertex of the feasible region must be evaluated and compared with each other vertex. For the example problem, the vertices of the feasible region are (0,0), (0,9), (1,9), (7,3), and (7,0). Evaluating each point according to the objective function $Z = 2X_1 + 3X_2$, it is clear that the point (1,9) provides the maximum value for the objective function. Thus, the solution is to set X_1 to 1 and X_2 to 9. This will result in the maximum attainable value of 29.



The previous example illustrates the basic procedure of LP, using a sample problem consisting of only 2 variables. For much larger problems, it is impossible to determine an optimal solution without the aid of a computer. The Army's scheduling problem has 8 decision variables, each corresponding to 18 time intervals. This results in over 18,000,000,000,000,000 possible points. Not all of these are vertex points, but the process of determining the vertex points would, in itself, be an ominous task. A similar analysis of the LP process for the Army's scheduling problem will not be presented for obvious reasons, but an abstract description of the objective formulation and corresponding constraints follows:

bjective:	Maximize Overall Proficiency Across All Applicable Skill Areas
ubject To:	Initial Performance Levels Degradation Times Proficiency Enhancement Levels Resource Availability Cost Constraints
	Bin Variables (0-1)

Appendix B

U.S. Army Training Methods

U.S. Army Training Methods

FTX - Field Training Exercise
- High relative cost and overhead due to intensive simulated combat conditions
- Exercise command & control of all echelons in battle functions--intelligence, CS, CSS, maneuver, and communications
- Provides the most realistic training environment of all methods

CFX - Combined Field Exercise
- Less expensive in terms of money, time, and personnel than an FTX
- Essentially an FTX with reduced combat unit and vehicle density

FCX - Fire Coordination Exercise
- Medium cost and overhead due to reduced scale exercise
- Concentration is generally on target acquisition

CPX - Command Post Exercise
- Medium cost and overhead
- Training for subordinate leaders and staffs at all echelons

MAPEX- Map Exercise
- Low cost and low overhead due to minimal equipment requirements
- Generally allows participation by units NOT at maximum proficiency

TEWT - Tactical Exercise Without Troops
- Very low cost and overhead
- Useful in analyzing terrain and employing units relative to analysis

STAFFEX
- Staff Exercise
- Relatively low cost and overhead
- Useful in practicing staff procedures

Sources: FM 25-101
FM 25-4

Appendix C

Rules for Deriving Training Method Utility

Rules for Deriving Training Method Utility

CATS data are arranged in a format such that each training method has both a "level of usefulness", as well as a designated prerequisite training gate. A training method's level of usefulness is rated "A", "B", "C", or "D", where "A" refers to a more highly structured, perhaps rigorous exercise and "D" indicates a less intense or non-applicable training method. Several methods require a unit to be at a specific proficiency level, or "training gate" of U, P, or T. For example, it is possible for a given training method to be useful only to a unit already at a given proficiency level for a specific skill area.

Methods of Level A or B:

Despite prerequisite training gates, a training method of level A or B is always sufficient to result in an increase in proficiency level, or sustainment in the case of an initially trained unit. Thus, after a level A or B exercise, a trained unit will *always* remain trained, a partially unit will *always* become trained, and an untrained unit will *always* become partially trained.

Methods of Level C

- Regardless of prerequisite training gates, a training method of level C is always adequate enough for a trained unit to remain trained.

- A training method of level C which requires a training gate of T will provide no utility to an untrained unit. This is based on the speculation that a training method geared towards a highly skilled unit will be of no use to a unit ignorant of the specific task. However, the same method will allow a partially trained unit to sustain at the P-level. It is assumed that this unit, while not completely proficient, will benefit some from the exercise.

  A training method requiring a gate of P, will increase both a partially trained unit and an untrained unit to their nexT-level of proficiency. A training method of level C, with no prerequisite gate, will sustain a unit at the P-level, and partially train an untrained unit.

Methods of Level D

- For an initially trained unit, regardless of the proficiency requirement, a training method of level D provides no training utility.
- A training method of level D will always sustain a partially trained unit, regardless of proficiency requirements.

For an untrained unit, if a training method of level D requires a prerequisite training gate of T, it is assumed to be of no use to the unit. However, a method of level D with no prerequisite gate or a prerequisite gate of P proficiency is substantial enough to partially train the previously untrained unit.

Appendix D

Training Method Costs

Overall Cost Estimates ($)

Total Cost / Event	
CPX/TEWT/MAPEX	1,219.84
CFX	239,717.47
FTX	651,727.88
FCX	10,843.25

	Mileage Cost per Event	Operational Cost per Event	Ammunition Cost per Event	Days per Event
CPX/TEWT/MAPEX	624.12	595.72	0.00	3
CFX	238,962.45	755.02	0.00	3
FTX	631,748.17	1,620.98	18,358.73	5
FCX	9,481.70	168.27	1,193.28	1

	Mileage Cost per Day	Operational Cost per Day	Ammunition Cost per Day
CPX/TEWT/MAPEX	208.04	198.57	0.00
CFX	79,654.15	251.67	0.00
FTX	126,349.63	324.20	3,671.75
FCX	9,481.70	168.27	1,193.28

	% of Total	Scaled 1-100
CPX/TEWT/MAPEX	0.00	0.19
CFX	0.27	36.78
FTX	0.72	100.00
FCX	0.01	1.66

Mileage Cost Estimates ($)

Mileage Cost / Day	
CPX/TEWT/MAPEX	208.04
CFX	79,654.15
FTX	126,349.63
FCX	9,481.70

Miles / Item

	Tank	APC	Carr 107M	Carr CPM5	Recy M88	Hemtt	HMM WV	Truck 09	Truck 94	Truck 31
CPX/TEWT/ MAPEX	0	0	0	0	0	0	21.7	5	0	0
CFX	23.3	36.7	21.3	21.3	16.7	12	51.7	18	26.7	16.7
FTX	14	23	14	13	10	14.4	52	28.4	40	13
FCX	3	0	0	0	1	1	4	3	6	1.5

Items / Day

	Tank	APC	Carr 107M	Carr CPM5	Recy M88	Hemtt	HMM WV	Truck 09	Truck 94	Truck 31
CPX/TEWT/ MAPEX	0	0	0	0	0	0	20	2	0	0
CFX	22	4	6	8	2	8	13	13	3	2
FTX	58	13	6	8	7	28	39	30	5	6
FCX	22	0	0	0	2	6	13	13	5	4

Miles / Day

	Tank	APC	Carr 107M	Carr CPM5	Recy M88	Hemtt	HMM WV	Truck 09	Truck 94	Truck 31
CPX/TEWT/ MAPEX	0	0	0	0	0	0	434	10	0	0
CFX	512.6	146.8	127.8	170.4	33.4	96	672.1	234	80.1	33.4
FTX	812	299	84	104	70	403.2	2028	852	200	78
FCX	66	0	0	0	2	6	52	39	30	6

Cost / Mile

Tank	APC	Carr 107M	Carr CPM5	Recy M88	Hemtt	HMM WV	Truck 09	Truck 94	Truck 31
140.03	9.85	11.19	11.65	62.81	2.97	0.46	0.84	1.1	1.1

Operation Cost Estimates ($)

Operation Cost / Day	
CPX/TEWT/MAPEX	198.57
CFX	251.67
FTX	324.20
FCX	168.27

Operation Time / Item

	Stm Clean	BCS	GENR	HEATER
CPX/TEWT/MAPEX	2	11.3	6	5.3
CFX	2	11.3	8	5.3
FTX	4	14.4	10	7.2
FCX	4	8.0	5	0.0

Items / Day

	Stm Clean	BCS	GENR	HEATER
CPX/TEWT/MAPEX	1	1	9	1
CFX	1	1	9	1
FTX	1	1	9	1
FCX	1	1	9	0

Operation Time / Day

	Stm Clean	BCS	GENR	HEATER
CPX/TEWT/MAPEX	2	11.3	54	5.3
CFX	2	11.3	72	5.3
FTX	4	14.4	90	7.2
FCX	4	8.0	45	0.0

Operation Time / Day

Stm Clean	BCS	GENR	HEATER
5.44	1.72	2.95	1.69

Ammunition Cost Estimates ($)

Ammunition Cost / Day	
CPX/TEWT/MAPEX	0
CFX	0
FTX	3,671.75
FCX	1,193.28

Rounds / Day

	A075	A080	A111	A598	G930	G940	G945	G950	G955
CPX/TEWT/ MAPEX	0	0	0	0	0	0	0	0	0
CFX	0	0	0	0	0	0	0	0	0
FTX	213.3	320	2320	1160	2.4	2.3	2.9	1.3	1.3
FCX	0	0	0	0	0	0	0	0	0

Cost / Round

A075	A080	A111	A598	G930	G940	G945	G950	G955
0.29	0.17	0.29	0.88	23.54	26.19	24.19	24.20	23.30

Rounds / Day

	G963	K867	L305	L306	L307	L311	L312	L314
CPX/TEWT/ MAPEX	0	0	0	0	0	0	0	0
CFX	0	0	0	0	0	0	0	0
FTX	0.9	0.4	0.4	0.4	0.5	0.4	1.3	0.9
FCX	0	0	0	0	0	0	0	0

Cost / Round

G963	K867	L305	L306	L307	L311	L312	L314
51.87	125.00	32.05	58.65	34.75	37.67	40.42	34.75

Rounds / Day

	L367	L495	L594	L595	L596	L600	L601	L602
CPX/TEWT/ MAPEX	0	0	0	0	0	0	0	0
CFX	0	0	0	0	0	0	0	0
FTX	44.7	1.2	9.7	0.9	0.5	1.5	7.5	208
FCX	0	0	0	0	0	0	0	528

Cost / Round

L367	L495	L594	L595	L596	L600	L601	L602
9.12	28.57	9.45	70.00	51.97	2.68	9.00	2.26

Appendix E

General Algebraic Modeling System (GAMS) Code

```
$title MOSES
*$offsymxref offsymlist;
options sysout = off, solprint = on, limcol = 0, limrow = 0,
iterlim = 250000, reslim = 250000, optca = 2;

SETS TASKS       /DEFEND, ACT, COMMAND, PLAN, PREP, EXEC,
                  COORD, MORTARS, ARTY, CAS, S2, CONDUCT,
                  COLLECT, PROCESS, DISSEM/
     METHODS     /STAFFEX, MAPEX, TEWT, FCX, CPX, CFX, FTX/
     TIME        /0*18/
     RATINGS     /U,P,T/
     QUARTERS    / 1 * 6 /
;

ALIAS(TIME,TT);

TABLE   PERFORM(TASKS,RATINGS,METHODS)

              STAFFEX   MAPEX   TEWT   FCX   CPX   CFX   FTX
DEFEND.T                               1     1     1     1
DEFEND.P                  1      1     2     2     2     2
DEFEND.U                  2      2     2     2     2     2
ACT.T            1                     1     1     1     1
ACT.P            2        1      1     2     2     2     2
ACT.U            2        2      2     2     2     2     2
COMMAND.T                                                1
COMMAND.P                                                2
COMMAND.U                                                2
PLAN.T           1                                       1
PLAN.P           2                                       2
PLAN.U           2                                       2
PREP.T           1                     1     1     1
PREP.P           2        1      1     2     2     2
PREP.U           2        2      2     2     2     2
EXEC.T           1                     1     1     1
EXEC.P           2        1      1     2     2     2
EXEC.U           2        2      2     2     2     2
COORD.T          1                     1     1     1     1
COORD.P          2        1      1     2     2     2     2
COORD.U          2        2      2     2     2     2     2
MORTARS.T        1                     1     1     1     1
MORTARS.P        2        1      1     2     2     2     2
MORTARS.U        2        2      2     2     2     2     2
ARTY.T           1                     1     1     1     1
ARTY.P           2        1      1     2     2     2     2
ARTY.U           2        2      2     2     2     2     2
CAS.T            1                     1     1     1     1
CAS.P            2        1      1     2     2     2     2
CAS.U            2        2      2     2     2     2     2
S2.T                                   1     1     1     1
S2.P                      1      1     2     2     2     2
```

```
S2.U                         2       2       2       2       2       2
CONDUCT.T           1                        1       1       1       1
CONDUCT.P           2        1       1       2       2       2       2
CONDUCT.U           2        2       2       2       2       2       2
COLLECT.T           1                        1       1       1       1
COLLECT.P           2        1       1       2       2       2       2
COLLECT.U           2        2       2       2       2       2       2
PROCESS.T           1                        1       1       1       1
PROCESS.P           2        1       1       2       2       2       2
PROCESS.U           2        2       2       2       2       2       2
DISSEM.T            1                        1       1       1       1
DISSEM.P            2        1       1       2       2       2       2
DISSEM.U            2        2       2       2       2       2       2
;

TABLE        DT(TASKS,RATINGS)                      DEGRADATION TIME

             T          P
DEFEND       3          4
ACT          3          4
COMMAND      3          4
PLAN         3          4
PREP         3          4
EXEC         3          4
COORD        3          4
MORTARS      3          4
ARTY         3          4
CAS          3          4
S2           3          4
CONDUCT      3          4
COLLECT      3          4
PROCESS      3          4
DISSEM       3          4
;
```

```
TABLE CORR(TIME, QUARTERS)

        1   2   3   4   5   6
     1  1
     2  1
     3  1
     4      1
     5      1
     6      1
     7          1
     8          1
     9          1
    10              1
    11              1
    12              1
    13                  1
    14                  1

    15                  1
    16                      1
    17                      1
    18                      1
;

$ONTEXT
*FOR SENSITIVITY ANALYSIS
TABLE        AVAIL(TIME,METHODS)                RANGE AVAILABILITY

                    STAFFEX  MAPEX   TEWT   FCX   CPX   CFX   FTX
0
1                                            1
2                              1             1
3                              1                               1
4
5                                                        1
6                      1
7                      1
8                                                  1
9
10                                                             1
11
12                             1      1
13                             1                               1
14
15                                                       1
16                     1
17                     1
18                                                 1
                                                                          ;
```

```
$OFFTEXT

TABLE          AVAIL(TIME,METHODS)       All methods available for all times.

                 STAFFEX MAPEX  TEWT    FCX     CPX     CFX     FTX
0                  1       1      1      1       1       1       1
1                  1       1      1      1       1       1       1
2                  1       1      1      1       1       1       1
3                  1       1      1      1       1       1       1
4                  1       1      1      1       1       1       1
5                  1       1      1      1       1       1       1
6                  1       1      1      1       1       1       1
7                  1       1      1      1       1       1       1
8                  1       1      1      1       1       1       1
9                  1       1      1      1       1       1       1
10                 1       1      1      1       1       1       1
11                 1       1      1      1       1       1       1
12                 1       1      1      1       1       1       1
13                 1       1      1      1       1       1       1
14                 1       1      1      1       1       1       1
15                 1       1      1      1       1       1       1
16                 1       1      1      1       1       1       1
17                 1       1      1      1       1       1       1
18                 1       1      1      1       1       1       1
;

TABLE          INITRATE(TASKS,RATINGS)

                   T       P      U
DEFEND                            1
ACT                               1
COMMAND                           1
PLAN                              1
PREP                              1
EXEC                              1
COORD                             1
MORTARS                           1
ARTY                              1
CAS                               1
S2                                1
CONDUCT                           1
COLLECT                           1
PROCESS                           1
DISSEM                            1
;
```

```
TABLE FTXCHK(TIME,TT)          Exclusion windows for FTX events

       1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18
   1   1  1  1  1  1  1  1  1  1  1  1  1
   2   1  1  1  1  1  1  1  1  1  1  1  1  1
   3   1  1  1  1  1  1  1  1  1  1  1  1  1  1
   4   1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
   5   1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
   6   1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
   7   1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
   8   1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
   9   1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  10   1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  11   1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  12   1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  13      1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  14         1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  15            1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  16               1  1  1  1  1  1  1  1  1  1  1  1  1  1
  17                  1  1  1  1  1  1  1  1  1  1  1  1  1
  18                     1  1  1  1  1  1  1  1  1  1  1  1
;


PARAMETER      COST(METHODS)     /STAFFEX 1220,MAPEX 1220,TEWT 1220,
                                   FCX 10843,CPX 1220,CFX 239717,
                                    FTX 651728/;
SCALAR         TOTBUDGET         /20000000/;
PARAMETER      QTRBUDGET(QUARTERS)
               / 1 4000000, 2 4000000, 3 4000000, 4 4000000,
                 5 4000000, 6 4000000 /;

BINARY VARIABLES       TRAIN(METHODS,TIME);

TRAIN.UP(METHODS,TIME) = AVAIL(TIME,METHODS);

POSITIVE VARIABLES  PERF(TASKS,RATINGS,TIME)
                    OFF(TASKS,RATINGS,TIME);

PERF.UP(TASKS,RATINGS,TIME) = 1;

OFF.UP(TASKS,RATINGS,TIME)
          $(ORD(RATINGS) NE 1 AND ORD(TIME) NE 1) = 1;
OFF.UP(TASKS,RATINGS,TIME)
          $(ORD(RATINGS) EQ 1 OR ORD(TIME) EQ 1) = 0;
OFF.UP(TASKS,RATINGS,TIME)
          $(ORD(TIME) LE DT(TASKS,RATINGS)) = 0;

VARIABLES           TOTAL          TOTAL PERFORMANCE
                    DOLLARS        TOTAL DOLLARS
;
```

```
EQUATIONS     INITIAL(TASKS,RATINGS,TIME)        INITIAL RATINGS
              INCRATE1(TASKS,RATINGS,TIME)       INCREASE TASK RATINGS 1
              INCRATE2(TASKS,RATINGS,TIME)       INCREASE TASK RATINGS 2
              REMRATE(TASKS,RATINGS,TIME)        REMAIN AT TASK RATING
              DECRATE(TASKS,RATINGS,TIME)        DECREASE TASK RATINGS
              TTOFF1(TASKS,RATINGS,TIME)         TASK TIME OFF UPPER
              TTOFF2(TASKS,RATINGS,TIME,TT)      TASK TIME OFF LOWER
              LIMIT1(TIME)                       LIMIT 1 METHOD PER WEEK
              LIMIT2(TASKS,TIME)                 LIMIT 1 RATING PER WEEK
              FIELD                              AT LEAST 1 FIELD EXERCISE
              TCOST                              Total training costs (full period)
              QTRCOSTS(QUARTERS)                 Quarterly training costs
              TAPERF                             TOTAL AVERAGE PERFORMANCE
              FTXLIM(TIME)                       Limit FTXs to 1 per 9 months
              TDOLLARS                           TOTAL COST
              PERFREQ                            MAXIMUM PERFORMANCE REQUIREMENT
;

INITIAL(TASKS,RATINGS,"0")..
    PERF(TASKS,RATINGS,"0") =E= INITRATE(TASKS,RATINGS);

INCRATE1(TASKS,RATINGS+1,TIME+1)..
    PERF(TASKS,RATINGS+1,TIME+1) =G=
         PERF(TASKS,RATINGS,TIME) + SUM(METHODS
                    $(PERFORM(TASKS,RATINGS,METHODS) EQ 2),
                    TRAIN(METHODS,TIME+1)) - 1;

INCRATE2(TASKS,RATINGS+2,TIME+1)..
    PERF(TASKS,RATINGS+2,TIME+1) =G=
         PERF(TASKS,RATINGS,TIME) + SUM(METHODS
                    $(PERFORM(TASKS,RATINGS,METHODS) EQ 3),
                    TRAIN(METHODS,TIME+1)) - 1;

REMRATE(TASKS,RATINGS,TIME+1)..
    PERF(TASKS,RATINGS,TIME+1) =G=
         PERF(TASKS,RATINGS,TIME) - SUM(METHODS
                    $(PERFORM(TASKS,RATINGS,METHODS) GT 1),
                    TRAIN(METHODS,TIME+1)) -
                    OFF(TASKS,RATINGS,TIME+1);

DECRATE(TASKS,RATINGS-1,TIME+1)..
    PERF(TASKS,RATINGS-1,TIME+1) =G=
         PERF(TASKS,RATINGS,TIME) + OFF(TASKS,RATINGS,TIME+1) - 1;

TTOFF1(TASKS,RATINGS,TIME+DT(TASKS,RATINGS)) $(ORD(RATINGS) NE 1)..
    OFF(TASKS,RATINGS,TIME+DT(TASKS,RATINGS)) =G=
              1 - SUM(TT $(ORD(TT) GT ORD(TIME)
              AND ORD(TT) LE ORD(TIME) + DT(TASKS,RATINGS)),
              SUM(METHODS $(PERFORM(TASKS,RATINGS,METHODS) NE 0),
                                                  TRAIN(METHODS,TT)));
```

```
TTOFF2(TASKS,RATINGS,TIME+DT(TASKS,RATINGS),TT)
     $(ORD(RATINGS) NE 1 AND ORD(TT) GT ORD(TIME) AND
            ORD(TT) LE ORD(TIME)+DT(TASKS,RATINGS))..
     OFF(TASKS,RATINGS,TIME+DT(TASKS,RATINGS)) =L=
                  1 - SUM(METHODS $(PERFORM(TASKS,RATINGS,METHODS)
                                 NE 0), TRAIN(METHODS,TT));

LIMIT1(TIME)..    SUM(METHODS,TRAIN(METHODS,TIME)) =L= 1;

LIMIT2(TASKS,TIME)..    SUM(RATINGS,PERF(TASKS,RATINGS,TIME)) =E= 1;


FIELD..    SUM(TIME$(ord(TIME) NE 1),TRAIN("FTX",TIME)) =G= 1;

FTXLIM(TIME) ..  SUM(TT$(FTXCHK(TIME,TT) EQ 1), TRAIN("FTX",TT)) =L= 1;

TCOST..    SUM(TIME,SUM(METHODS,TRAIN(METHODS,TIME)*COST(METHODS)))
                                                =L= TOTBUDGET;

QTRCOSTS(QUARTERS) .. SUM(TIME$(CORR(TIME,QUARTERS) NE 0),
                     SUM(METHODS,TRAIN(METHODS,TIME) * COST(METHODS)))
                                                =L= QTRBUDGET(QUARTERS);

TAPERF..    TOTAL =E= SUM(TIME $(ORD(TIME) GT 1),
                             SUM(TASKS,PERF(TASKS,"T",TIME)));

PERFREQ..    TOTAL =G= 236;

TDOLLARS..    DOLLARS =E=
                   SUM(TIME,SUM(METHODS,TRAIN(METHODS,TIME)*COST(METHODS)));

MODEL STRATEGY /ALL/;
*strategy.cutoff = 820;
STRATEGY.OPTFILE = 1;
SOLVE STRATEGY USING MIP MAXIMIZING TOTAL;
SOLVE STRATEGY USING MIP MINIMIZING DOLLARS;

$ontext
*Original version (excludes ordinate 0 time period, but if
*no method is scheduled, as appropriate, it will not show anyway)
FILE METH /FM_CAC3.DAT/;
PUT METH;
LOOP((TIME,METHODS) $(ORD(TIME) NE 1),
PUT $(TRAIN.L(METHODS,TIME) EQ 1) TIME.TL, METHODS.TL /;
);

FILE RAT /FR_CAC3.DAT/;
PUT RAT;
LOOP((TASKS,TIME,RATINGS) $(ORD(TIME) NE 1),
PUT $(PERF.L(TASKS,RATINGS,TIME) EQ 1) TIME.TL, TASKS.TL,
RATINGS.TL /;
);
```

```
FILE METH /FM_CAC3.DAT/;
PUT METH;
LOOP((TIME,METHODS),
PUT $(TRAIN.L(METHODS,TIME)) TIME.TL, METHODS.TL /;
);

FILE RAT /FR_CAC3.DAT/;
PUT RAT;
LOOP((TASKS,TIME,RATINGS),
PUT $(PERF.L(TASKS,RATINGS,TIME)) TIME.TL, TASKS.TL,
RATINGS.TL /;
);
$OFFTEXT


FILE METH /FM_TST3.DAT/;
PUT METH;
LOOP((TIME,METHODS),
PUT $(TRAIN.L(METHODS,TIME) EQ 1) TIME.TL, METHODS.TL /;
);

FILE RAT /FR_TST3.DAT/;
PUT RAT;
LOOP((TASKS,TIME,RATINGS),
PUT $(PERF.L(TASKS,RATINGS,TIME) EQ 1) TIME.TL, TASKS.TL,
RATINGS.TL /;
);
```